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Impact of astronomical research from different countries

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Abstract. The impact of astronomical research carried out by different countries has been compared by analysing the 1000 most-cited astronomy papers published 1991-8 (125 from each year). 61% of the citations are to papers with first authors at institutions in the USA, 11% in the UK, 5% in Germany, 4% in Canada, 3% in Italy and 3% in France. 17% are to papers with first authors in ESO countries. The number of citations is approximately proportional to the number of IAU members in a given country. The number of citations per IAU astronomer is highest in the USA, Switzerland and the UK. Within continental Europe, the number of citations per IAU astronomer varies little from country to country, but is slightly higher in the north than in the south. The sample of 1000 papers maps regional subject preferences. 62% of the extragalactic papers in the sample were published from the USA, 15% from the UK, 23% from other countries (mainly in continental Europe). 62% of the papers on stars were also published from the USA, but the fractions from the UK and from other countries are 2% and 36% respectively.

Key words: scienciometric; bibliometric; scientific productivity

1. Introduction

Nearly all developed countries support vigorous programmes of research in astronomy, but there have been few comparisons of the relative scientific impact of astronomical research in different countries. Research environments and strategies differ from country to country, so a detailed comparison may shed light on which policies are more successful.

A list of the 125 most-cited astronomy/space papers for each year 1991-8, 1000 papers in all, was purchased from the Institute for Scientific Information (ISI) in Philadelphia. In Benn & Sanchez (2001, hereafter Paper I), we used these data to compare the scientific impact of different telescopes. Here we use the same dataset to compare the scientific impact of research from different countries. See Paper I for details of the sample and analysis, and also for a discussion of the various biases which affect citation anlayses. Biases against both publication and citation need to be considered when comparing citation counts for different countries. Language bias operates at a number of levels. (1) A requirement to publish in English favours native speakers of the language. (2) English-speaking scientists tend not to read or cite papers written in other languages (e.g. Rees 1997, Nature 2002b). (3) Citation databases provide uneven coverage of foreign-language journals (e.g. Ziman 2001, Moed 2002). A separate bias arises from the tendency of each community to over-cite its own results, e.g. through preferentially reading and citing national journals (e.g. Durrani 2000 found that papers from large countries receive more citations than papers from small countries). These biases are likely to favour over-citation of papers from the large north American and UK astronomy communities.

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2. Citation impact by country

Each of the 1000 top-cited papers was credited to the country of the institution hosting the first author. The number of papers generated by each country, and the corresponding fractions of citations are given in Table 1. The breakdown of citation fractions by country is shown in Fig. 1. In Fig. 2, we compare the citation fractions for each country with four measures which are likely to correlate with the resources invested by that country in astronomical research: the number of IAU members; the country's share of all-science citations; gross domestic product (GDP); and total population (CIA, 1999). The number of citations is approximately proportional to the number of IAU members in each country, and to the country's all-science citation share, over 2 orders of magnitude (Figs. 2a, b). The correlations with GDP and total population (Figs. 2c, d) are weaker (i.e., larger dispersion), as one would expect, given that countries spend different fractions

Table 1. Citation impact by country, for all countries with at least one paper in the top-cited 1000 published 1991-8

Country (1)	ISO code (2)	ΣPapers top-1000 (3)	ΣCitns% top-1000 (4)	All astro papers% (5)	IAU mem (6)	Citns% /100 IAU (7)	Science % (8)	GDP $\$10^9$ (9)	Popn. 10^6 (10)	IAU/ 10^6 popn. (11)
Australia	AU	18	1.6	3.3	191	0.8	2.2	393	18.8	10.2
Austria	AT	1	0.1		31		0.7	184	8.1	3.8
Belgium	BE	2	0.2	1.1	88		1.1	236	10.2	8.6
Brazil	BR	2	0.1		109		0.6	1035	171.1	0.6
Canada	CA	40	3.8		199	1.9	4.3	688	31.0	6.4
Chile	CL	5	0.4		46		0.2	184	15.0	3.1
Denmark	DK	6	0.7		52	1.3	1.0	124	5.4	9.6
Estonia	EE	1	0.1		22		0.0	7	1.4	15.7
Finland	FI	1	0.1		37		0.8	103	5.2	7.1
France	FR	35	2.9	8.7	609	0.5	5.7	1320	59.0	10.3
Germany	DE	56	4.9	11.7	488	1.0	7.2	1813	82.1	5.9
Israel	IL	3	0.3	1.1	45		1.1	101	5.8	7.8
Italy	IT	31	3.2	7.2	409	0.8	3.4	1181	56.7	7.2
Japan	JP	23	2.4	5.1	448	0.5	8.2	2903	126.2	3.5
Netherlands	NL	23	2.1	3.9	167	1.3	2.3	348	15.8	10.5
Poland	PL	4	0.4		117		0.9	263	38.6	3.0
Russia	RU	2	0.1		344		4.1	593	146.4	2.3
S.Africa	ZA	3	0.4		46		0.4	290	43.4	1.1
S.Korea	KR	1	0.1	0.4	51		0.5	585	46.9	1.1
Spain	ES	7	0.8	4.4	204	0.4	2.0	645	39.2	5.2
Sweden	SE	4	0.6		95		1.8	175	8.9	10.7
Switzerland	CH	14	1.9		70	2.7	1.6	191	7.3	9.6
UK	UK	101	10.7	10.3	535	2.0	7.9	1252	59.1	9.1
Ukraine	UA	2	0.2		119		0.6	108	49.8	2.4
USA	US	599	60.6	42.9	2235	2.7	30.8	8511	272.6	8.2
Venezuela	VE	2	0.3		9		0.1	194	23.2	0.4
ESO		171	16.5	32.6	1978	0.8	24.1	5388	245.4	8.1

Columns 1 – 2 give the country name and ISO code (the latter used as a plot symbol in Figs. 1 and 2). Column 3 – 4 give the number of the top-cited 1000 articles with first author hosted by the given country, and the citation fraction (column 4 sums to 100%). Column 5 gives the percentage of *all* astronomical articles published (from the ISI web pages). Columns 6 – 7 give the number of IAU members (from the IAU bulletin of June 1998) and, for countries with more than 5 papers (column 3), the citation fraction (column 4) per 100 IAU members. Columns 8 – 11 give the all-science citations fraction (Gibbs 1995, similar numbers are presented by May 1997), annual gross domestic product (GDP), total population (CIA, 1999), and number of IAU members per million population. The last line of the table is a sum over ESO countries (Belgium, Denmark, France, Germany, Italy, the Netherlands, Sweden and Switzerland, in 1999). 14 of the 1000 papers could not be classified by country (mostly because they were published in solar-physics journals to which we did not have access).

of their wealth on research. In particular, research in countries with GDP per capita $<$ \$15000 (circled on Fig. 2) yields fewer citations per unit GDP, i.e. these countries probably invest a smaller fraction of GDP in astronomical research.

The USA dominates, receiving 61% of the citations to the top 1000 papers, considerably higher than its all-science share of citations, 31%. It receives more astronomy citations per IAU member, per unit GDP or per head of population than most other countries. The UK comes second (11% of citations), followed by Germany (5%), Canada (4%), Italy (3%), France (3%), Japan (2%), the Netherlands (2%), Switzerland (2%) and Australia (2%). The statistics for the other countries are based on too few papers to permit a meaningful ranking. The sum for ESO countries (8 members during the period covered) is 17% (so it should rise to $\sim$ 27% with the admission to ESO of the UK). The split 61% USA, 11% UK, 18% continental Europe, 10% rest of the world is almost unchanged if just the top 10 most-cited papers from each year (i.e. 80 papers in all) are considered: 64% USA, 14% UK, 12% continental Europe, 10% rest of the world

For a nearly independent measure of impact, we looked at the 452 observational astronomy/space papers published in Nature (i.e. high-impact papers) during 1989-98. 52% of these had first authors at institutions in the USA, 13% in the UK, 20% in continental Europe, 15% rest of the world, similar to the fractions above.

There were no significant changes in the citation fractions from the 10 most-productive countries between 1991-4 and 1995-8. The statistics are too small to allow a comparison for the remaining countries. For science overall, output is growing fastest in Spain, according to Nature (1999), and the fraction of astronomy papers published from Spain is rising steadily (Sánchez & Benn 2001).

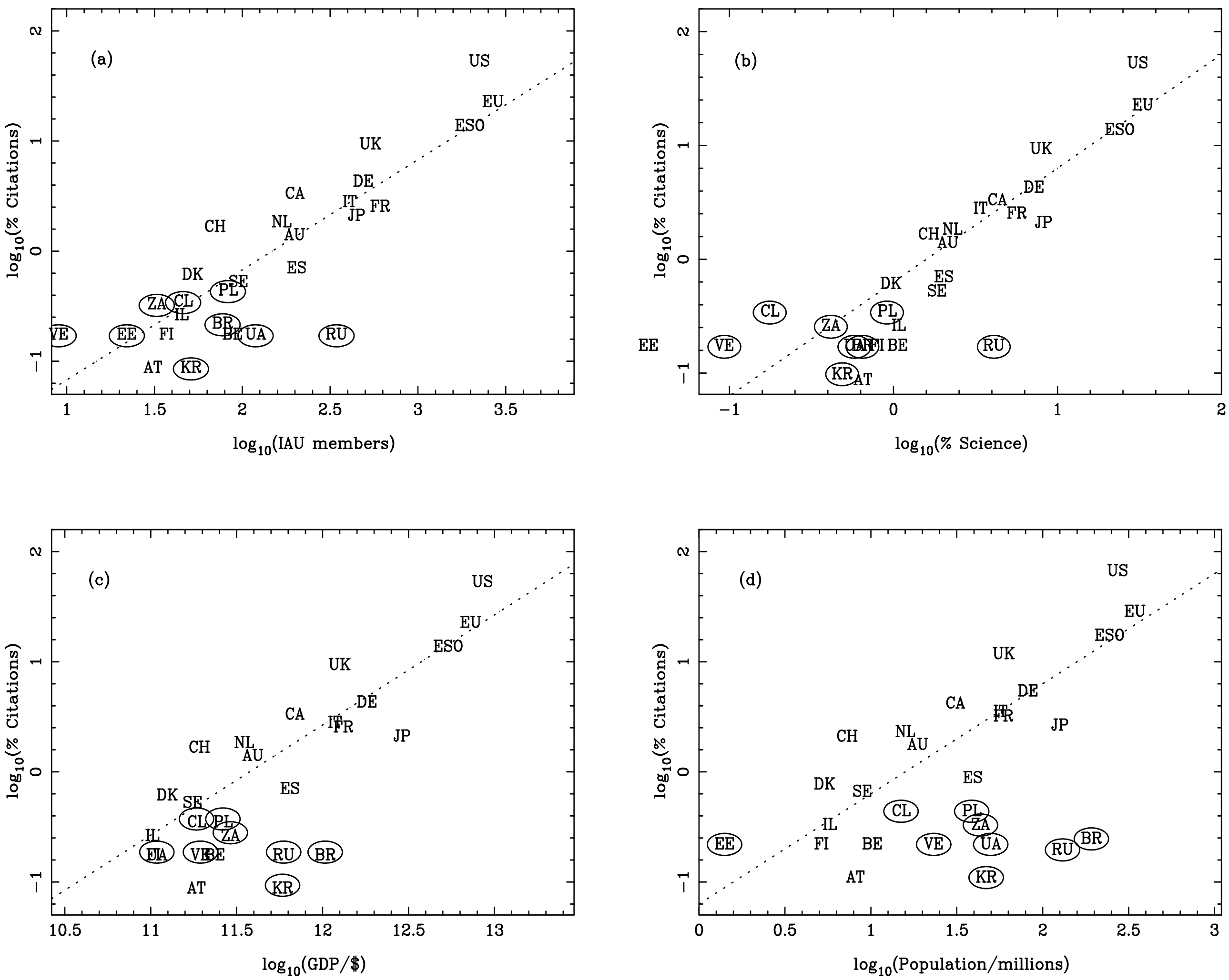

Fig. 2. Citation fraction 1991-8 for each country, compared with (a) IAU membership, (b) world share of all science citations, (c) gross domestic product (GDP) in \$, (d) country population. The dotted lines have slope 1 and their vertical positions are arbitrary. The point 'ESO' is a sum over the (then) 8 ESO member countries: BE, DK, FR, DE, IT, NL, SE, CH. The point 'EU' is a sum over the European Union countries included in Table 1: BE, DK, FR, DE, IT, NL, PT, ES, SE and UK. Circles indicate countries with GDP per capita $<$ \$15000 per year.

2.1. Citations per astronomer

The number of IAU members hosted by a given country is an imperfect measure of the resources invested in astronomy, because of country-to-country variations in the way IAU members are put forward. However, countries with a high citation fraction per IAU member, e.g. the Netherlands or Switzerland (Fig. 2a), tend also to have high citation fractions per unit all-science fraction, GDP or population (Figs. 2b,c,d), suggesting that the scatter about the mean in Fig. 2a is dominated by differences in mean citation fraction per unit investment in astronomy, rather than errors in the way that investment is measured.

Citation fraction per 100 IAU members (column 7 of Table 1) is relatively high in the USA (2.7%) and the UK (2.0%), probably in part due to the biases mentioned earlier (such as language and regional biases). The mean for the other major contributors (continental Europe, Australia, Canada and Japan) is 0.8 $\pm$ 0.1% per 100 IAU members, and varies little from country to country, despite the large variations in scientific culture, and in susceptibility to citation bias. Mean citation counts for different regions are shown in Table 2.

Within continental western Europe, where the effects of biases against citation counts are likely to be relatively homogeneous, differences in citations per astronomer between regions might trace the effects of different research cultures. To test this, we split Europe into two regions, roughly north vs south. The countries in the north of Europe (Austria, Belgium, Denmark, Finland, Germany, Netherlands, Sweden and Switzerland, 1017 IAU members, 7.5 per million of inhabitants) received a mean of 1.04 $\pm$ 0.10% of the citations per 100 IAU members. The countries of the south, (France, Italy and Spain, 1222 IAU members, 7.9 per head of population) received a mean of 0.56 $\pm$ 0.06% of the citations per 100 IAU members. The north / south ratio between these numbers is 1.86 $\pm$ 0.27. The north / south ratios of citation fractions per unit GDP and per unit population are 1.52 and 1.76 respectively (with similar fractional errors). The difference be-

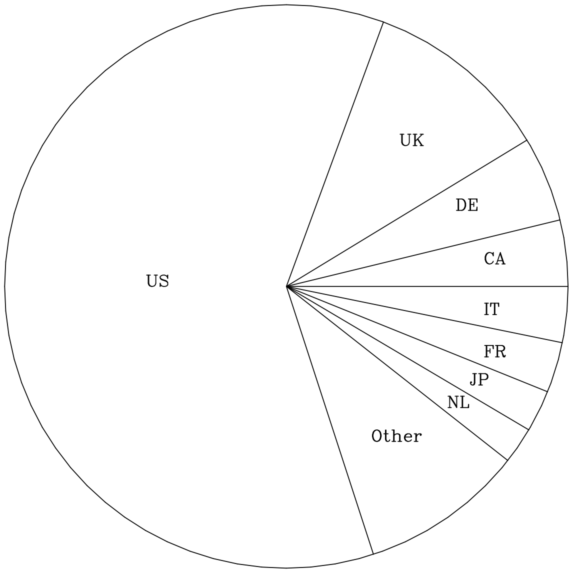

Fig. 1. Citation fractions for papers published 1991-8 from each country. The countries are represented by their 2-character ISO codes, as given in Table 1.

Table 2. Citation counts per IAU member, by region

Countries	Citations fraction /100 IAU members	Inbreeding fraction (%)
US	2.70 ± 0.10	–
UK	2.00 ± 0.20	5
CA	1.90 ± 0.30	–
AT BE DK FI DE NL SE CH	1.00 ± 0.10	22
AU	0.80 ± 0.20	–
FR IT ES	0.60 ± 0.10	73
JP	0.50 ± 0.10	–
Developing world	0.03 ± 0.01	–

Column 3 gives for each group of countries the mean fraction of teaching staff who trained at the universities where they currently hold a post (Soler 2001, see text).
'Developing world' includes developing countries with more than 100 IAU members in 1998: Brazil, China (no papers in top 1000), India (no papers in top 1000), Russia, Ukraine. The quoted errors are measurement $\times$ (number of papers)$^{-0.5}$.

tween north and south is small but mildly significant. It might be attributed to a number of factors, e.g.: different fractions of resources allocated through competitive peer review; relative emphasis on funding research in research institutions vs universities (see e.g. May 1997); or openness of competition for posts. The last of these is a matter of particular concern in France (e.g. Goodman 2001), Italy (e.g. Abbott 2001, Chiesa & Pacifico 2001, Nature 2001, Nature 2002a) and Spain (e.g. Bosch 1998, Bosch 1999, Escartin 1998, Pickin 2001). For a proxy measure of openness of recruitment, we used the fraction of university teaching staff who were trained at that university (Navarro & Rivero 2001), as measured by Soler (2001) for zoology and ecology departments. High 'inbreeding' fractions are likely to reflect a tendency to favour internal candidates, i.e. to allocate posts on grounds other than scientific merit. Soler (2001) measured this fraction for several countries: Spain (88%), Italy (78%), Austria (73%), France (65%), Belgium (52%), Finland (48%), the Netherlands (40%), Denmark (39%), Sweden (32%), Switzerland (23%), the UK (5%) and Germany (1%). The citation counts per IAU member are compared in Table 2 with the inbreeding fractions.

The fractions of citations per IAU member in Australia and Japan are similar to those in Europe, and are less than those in the USA and UK, consistent with language bias being less important than biases arising from being part of a large self-citing community.

The USA and Switzerland received the largest fraction of citations per IAU member. May (1997) found that Switzerland also leads the world in terms of numbers of all-science papers or citations per head of population.

The citation fraction per IAU member in the developing world is lower, probably due to many factors, including lack of resources, loss of expertise abroad, and langauge and other biases mentioned in the introduction. In addition, our arbitrary assignment of the citation credit for each paper to the country hosting the first author may bias against developing countries whose astronomers usually work as part of large international teams.

In Fig. 3 we compare the citation fraction for each country with the fraction of all astronomy articles published. The USA dominates, and the ratio of the two measures is higher for the USA than for other countries. When papers from the USA are excluded (Fig. 3b), the two fractions for each country are similar, i.e. number of papers published is a useful proxy for scientific impact.

2.2. Regional subject preferences

The sample of 1000 most-cited papers maps regional preferences for different areas of research. Of the papers on stars and on our galaxy, 62% are published from the USA, 2% from the UK and 36% from other countries. Similar regional distributions are obtained when this subset of papers is further sub-divided into papers on hot stars, on cool stars or on the galaxy. Papers on external galaxies split 56% USA, 21% UK, 23% other. Papers on AGN and cosmology split 65% USA, 12% UK, 23% other. Within the 1000-paper sample, the USA is relatively strongest in cosmology, the UK in studies of external galaxies, Europe in studies of cool stars.

These regional differences are reflected in the way individual telescopes were used. During the period studied, 1991-98, the most productive ground-based telescopes were of 4-m class. 189 of the 1000 top-cited articles were based on data from such telescopes: 143 with first author from the USA, 28 from the UK and 18 from continental Europe. For 4-m telescopes whose users are predominantly from North America, 98 of the 134 (73%) papers are on extragalactic topics. For 4-m telescopes used by the UK (WHT, AAT), the fraction is 28 out of 33 (85%). For 4-m telescopes whose users are predominantly from continental Europe (Calar Alto 3.5m, NTT 3.5m and ESO 3.6m), 8 of the 18 papers (44%) are on extragalactic topics.

These regional differences are also reflected in the extragalactic fraction in different journals: 62% of the subset of the top 1000 papers were published in ApJ, 83% of those published in MNRAS, 30% of those in A&A. If galactic and extragalactic astronomers had different citation practices, these differences could induce a regional bias in the citation counts. To test this, we counted the number of references in 25 of the papers from each of the US extragalactic and European (non-UK) stellar communities. The numbers of references ranged (excluding smallest and largest sixth, i.e. approximating $\pm$ 1 standard deviation for a gaussian) between 37 and 79 for extragalactic papers and between 24 and 78 for galactic ones. This suggests that any difference in citing rate between the two communities is small, and that the regional differences in preferred topics won't bias the citation count.

The emphasis on astrophysics, relative to science as a whole, also varies from country to country. The ISI web pages listed for each country the fraction of papers published in each of 22 disciplines, for the period $\sim$ 1994-8. The USA published $\sim$ 30% of all science and social-sciences papers worldwide, but $\sim$ 40% of all astrophysics papers. In terms of fraction of world output published, astrophysics ranks 6th in the USA (law is first, with 90% of world output, followed by four social-science subjects). In France, Germany, Italy, Netherlands, Spain and the UK, astrophysics ranks first, i.e. is the discipline in which each country publishes a larger fraction of world output than in any other discipline. In Japan, astrophysics ranks 15th.

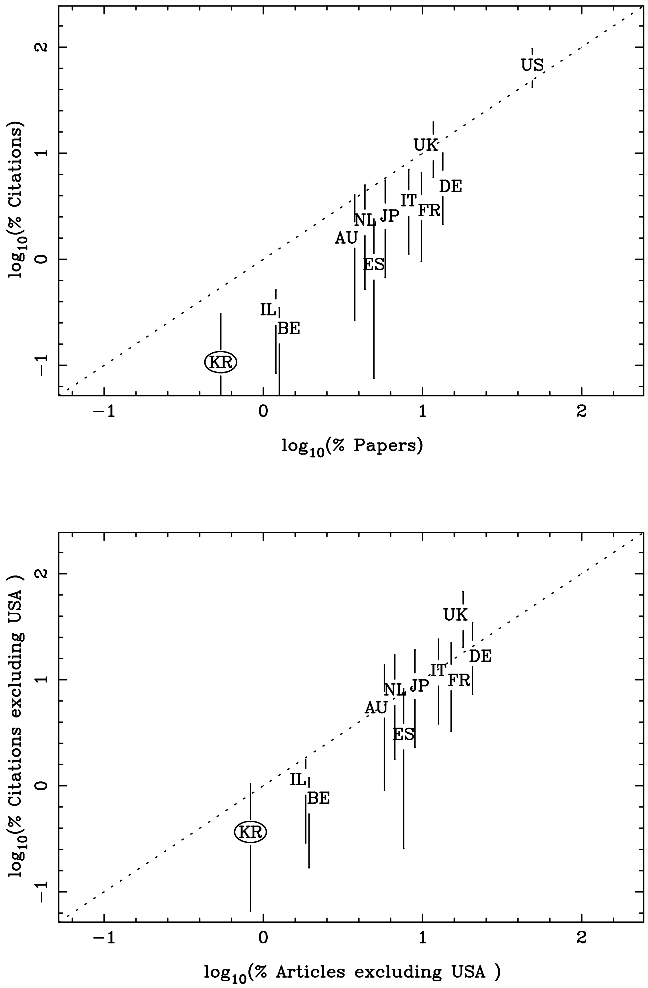

Fig. 3. (a) Relation between citation fraction (to 1000 most-cited articles) and fraction of *all* articles published in astronomy 1991-8 (data from ISI web page). (b) Same data as (a), but after excluding papers from the USA. In both panels, the error bars are measurement $\times$ (number of papers)$^{-0.5}$.

3. Conclusions

From our analysis of the 1000 most-cited astronomy papers published during 1991-98 we conclude:

1. 61% of the citations are to papers with first authors at institutions in the USA, 11% in the UK, 5% in Germany, 4% in Canada, 3% in Italy, 3% in France. 17% are to papers with first authors at institutions in (then) ESO countries. Language and other biases favour relative over-citation of papers from the large north-American and UK communities.
2. The number of citations generated by research in developed countries is proportional to the number of IAU members, over a range of 2 orders of magnitude, with rms $\approx$ 0.2 dex. The number of citations per astronomer is highest for the USA, with 2.7% of all citations per 100 IAU members. The number of citations per IAU member is similar for Canada and the UK. The mean for continental Europe is 0.8% per 100 IAU members, and is significantly higher in the north than in the south.
3. For most countries, citation fraction is similar to the fraction of all astronomy papers published by that country, i.e. the latter is a useful proxy for scientific impact.
4. Citation fraction is proportional to GDP for countries with GDP $>$ \$ 15000 per capita.
5. 62% of the extragalactic papers in the sample are published from the USA, 15% from the UK, 23% from other countries (mainly in Europe). In stellar astronomy, 62% of the papers are again published from the USA, but 2% from the UK, and 36% from other countries. Several metrics indicate a regional difference in relative emphasis on extragalactic and stellar research, with extragalactic work dominating in the USA and UK, and a greater emphasis on stellar work in Europe.

During the period 1991-8 covered by this study, ground-based optical astronomy was dominated by 4-m class telescopes. Since then, several 8-m class telescopes (e.g. Gemini, HET, Keck, Subaru, VLT) have come into use, and more are on the way (e.g. GTC, SALT). These will give 8-m access to countries which previously had only limited access to 4-m telescopes (e.g. Japan) and to countries whose astronomy communities are still expanding rapidly (e.g. Spain). It will therefore be interesting to repeat this study once there are enough citations to papers from the new 8-m telescopes to permit statistical analysis.

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